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(54) Optical measurement system for determination of an object's profile

Optisches Messsystem zur Ermittlung des Profils eines Gegenstandes

Système de mesure optique pour déterminer le profil d'un objet

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(56) References cited:
EP-A- 0 150 408
EP-A- 0 291 394
US-A- 4 298 286

Description

TECHNICAL FIELD

The present invention is directed to an optical measurement system for determination of an object's profile and more particularly to such an optical measurement system using two optical heads directing individual light beams to different points on the object's surface to measure distances of these points from a reference plane by triangulation for analyzing the surface profile of the object based upon the measured distances of the two points on the object's surface.

BACKGROUND ART

In order to obtain a depth or height of a step on the surface of an object or thickness of an object by optical triangulation measurement, it has been proposed to use a pair of optical heads disposed to direct individual light beams to different points on the object's surface for measuring the positions of these points. The distances of these points are processed by triangulation and are analyzed to determine the object profile. For example, when the two heads are disposed to measure the positions of the points spaced along the object's surface for measuring individual perpendicular distances to the surface from a reference plane, the difference of the measured distances gives the height or depth of a step existing between these two points. On the other hand, when the optical heads are disposed on the opposite of the object to measure like perpendicular distances of the positions of two points on the opposite surfaces of the object from a reference plane selected to be within the thickness of the object, the addition of the measured distances gives a thickness of the object at these points.

In such optical measurement system, the optical head is normally designed to have a photo-sensor which receives the light beam reflected on a point on the object's surface and provides an output which varies in proportion to the perpendicular distance of the point from a reference plane selected to be generally parallel to the object's surface. The output from the head is processed in an associated signal processing circuit so as to determine a true distance of the point from the reference plane. In this connection, when the two heads are connected to the individual signal processing circuits, there is a potential problem that the distances measured in these separate processing circuits may include individual deviations or discrepancies due to inherent variations in the circuits, for example, temperature characteristic of certain elements consisting the circuits. Since these discrepancies are inherent to the individual circuits, they are difficult to be compensated for in obtaining the step in the object's surface and the thickness of the object. Thus, no reliable analysis is not expected in this system having two optical heads connected respectively to the individual processing circuits.

EP-A-0150408 discloses an optical measurement system for the remote measuring of an object. The system includes first and second optical heads arranged to transmit light on to the surface to be monitored, and to provide first and second outputs which vary in proportion to the perpendicular distance from the reference plane to a first and second point on the object's surface. The outputs are separately processed to provide an indication of the thickness of the object.

"The Art of Electronics" second edition, published by Cambridge University Press, 1989, pages 143 to 144 in an article by Paul Horowitz and Winfield Hill discloses a multiplexer which enables the selection of any of several inputs as specified by a digital control signal.

The above problem has been eliminated in the present invention which provides an improved optical measurement system for determination of the depth of a step in the profile of an object.

According to a first aspect of the present invention there is provided an optical measurement system for determination of the depth of a step in a profile of an object, said system comprising:

a first optical head including light projector means for directing a first light beam on to a first point on a surface of the object and including photo-sensor means arranged to receive reflected light from said first point on the surface, and to provide a first output which varies in proportion to the perpendicular distance from a reference plane to said first point on the object's surface;
a second optical head including light projector means for directing a second light beam on to a second point on said surface of the object, and including photo-sensor means arranged to receive reflected light from said second point on the surface, and to provide a second output which varies in proportion to the perpendicular distance from a reference plane to said second point on the object's surface; and
circuitry for analysing the surface of the object based upon said first and second outputs,

said system being characterised in further comprising:

switch means for selectively connecting said first and second outputs to a single processing circuit, said single processing circuit being operable to process said first and second outputs in sequence to measure by triangulation the perpendicular distances of said first and second points from said reference plane, and to subtract the perpendicular distances thereby to determine the depth of the step in the profile of the object.

According to a second aspect of the present invention there is provided an optical measurement method for determination of the depth of a step in a profile of an object, said method using:

a first optical head including light projector means directing a first light beam to a first point on a surface of the object and including photo-sensor means receiving a reflected light from said first point on the surface and providing a first output which varies in proportion to a perpendicular distance from a reference plane to said first point on the object's surface; a second optical head including light projector means directing a second light beam to a second point on said surface of the object and including photo-sensor means receiving a reflected light from said second point on the surface and providing a second output which varies in proportion to a perpendicular distance from a reference plane to said second point on the object's surface; said method being characterised by the use of:

a single processing circuit capable of processing said first and second outputs to measure by triangulation the perpendicular distances of said first and second points respectively from said reference plane and analysing a surface of the object based upon thus measured perpendicular distances,

said method comprising delivering said first output from said first optical head to said common processing circuit for determination of said first perpendicular distance and then delivering said second output from said second optical head to said common processing circuit for determination of said second perpendicular distance, and subtracting said first and second perpendicular distances thereby to determine the depth of the step in the profile of the object.

With the use of the single processing circuitry to commonly process the first and second outputs from the first and second optical heads, the positions or perpendicular distances of the first and second points can be obtained through the identical triangulation processing, which gives reliable measurements for the perpendicular distances of the first and second points, thereby assuring correspondingly reliable determination of the surface profile of the object based upon thus measured perpendicular distances.

Accordingly, it is a primary object of the present invention to provide an improved optical measurement system which is capable of assuring reliable determination of the surface profile of the object.

In a preferred embodiment, the first and second optical heads are controlled to project the first and second light beams as pulse modulated ones in sequence such that only one of the first and second light beams is directed to the object surface at a time. With this result, it is readily possible to avoid any interference between the first and second light beams, in addition to well discriminate the light beam from the optical heads from a background illumination. Thus, more reliable determination can be achieved without suffering from interference between the light beams from the first and second optical heads and from the background illumination, which is therefore another object of the present invention.

In another preferred embodiment, the first and second optical heads are controlled to project first and second light beams which are pulse modulated to have different oscillating frequencies from each other. With this scheme, it is also possible to avoid interference between the light beams of the first and second optical heads as well as from the background illumination, yet without requiring a sequence control of directing the light beams in sequence from the first and second optical heads, which is therefore a further object of the present invention.

The processing circuit includes a calibrator which compensates for variations in the perpendicular distances measured respectively with respect to the first and second outputs when directing the first and second light beams to the first and second points selected on an optical flat plane parallel to the reference plane. Thus, possible misalignment between the first and second optical heads can be readily compensated for to thereby improve measurement reliability, which is therefore a still further object of the present invention.

Preferably, each of the modulated first and second light beams is configured to have high and low levels alternating to each other so that the corresponding one of the first and second optical heads produces high and low level values with respect to each of the first and second outputs. Thus obtained high and low level values are processed in the processing circuit to obtain a difference therebetween. The difference is used in the processing circuit as a true value for each of the first and second outputs to measure the perpendicular distance of each of the first and second points. In this scheme, therefore, the system can successfully cancel any errors resulting from background illumination as well as from variations in the characteristics of the elements forming the processing circuity.

It is therefore another object of the present invention to provide an improved optical measurement system which is capable of assuring reliable measurement substantially free from being influenced from the background illumination and characteristic variations in the elements forming the processing circuit.

The processing circuit is also configured to invalidate the measurement of the first and second distances when the high level value exceeds a predetermined maximum level or the low level value falls below a predetermined minimum level. That is, when the high and low level values are out of a workable range given to the processing circuit, the system itself can acknowledge erroneous measurement and disregard the measured results for retaining reliable measurement, which is therefore a further object of the present invention.

These and still other objects and advantageous features of the present invention will become more apparent

from the following description of the preferred embodiments when taken in conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS.

FIG. 1 is a schematic diagram of an optical measurement system in accordance with a first embodiment of the present invention, the system shown for measurement of a step in an object surface;
FIG. 2 is a schematic view illustrating a semi-conductor position sensor device (PSD) employed in the above system;
FIG. 3, composed of FIGS. 3A to 3G, is a timing chart illustrating the operation of the above system;
FIG. 5 is a schematic diagram of an optical measurement system in accordance with a second embodiment of the present invention;
FIG. 6 is a schematic diagram of an optical measurement system in accordance with a third embodiment of the present invention;
FIG. 7, composed of FIGS. 7A to 7C, is a timing chart illustrating control signals utilized in a processing circuit of the system;
FIG. 8, composed of FIGS. 8A and 8B, is a waveform chart illustrating the operation of the processing circuit of FIG. 6;
FIG. 9, composed of FIGS. 9A and 9B, is a waveform chart illustrating another operation of the processing circuit of FIG. 6;
FIG. 10 is a schematic diagram illustrating a fourth embodiment in accordance with the present invention; and
FIG. 11 is a schematic circuit diagram illustrating an operation of a supervising section incorporated in the system of FIG. 10.

DETAILED DESCRIPTION OF THE INVENTION

First embodiment <FIGS. 1 to FIG. 3>

Referring now to FIG. 1, there is shown an optical measurement system in accordance with a first embodiment of the present invention. The system includes two optical heads, namely, first optical head **10** and second optical head **20**, and a processing circuit **40** connected through a switch **31** to the first and second optical heads **10** and **20**. The first and second optical heads **10** and **20** are provided to measure two positions on an object's surface for determination of the object's surface. In FIG. 1, the system is adapted to determine a depth D of a step in the object surface in such a manner as to measure the positions or perpendicular distances D_1 and D_2 of two spaced points from a reference plane PLref by the individual optical heads **10** and **20** and obtain the difference between D_1 and D_2 as the depth D of the step ($D = D_1 - D_2$). Such measurement or determination of the step's depth is usually made with the object running in along the length of the step or in the direction perpendicular to the sheet relative to the first and second optical heads **10** and **20** which are normally fixed. The lateral distance between the optical heads **10** and **20** are suitably selected to measure the positions of the object's surface on both side of the step. In this connection, the heads **10** and **20** are supported on a suitable frame (not shown) and are held movable relative to each other in order to adjust the lateral distance. Further, the heads **10** and **20** are movable toward and away from the object surface for fine position adjustment.

The depth of the steps can be continuously determined so as to check variations thereof along one dimension of the object.

The first and second optical heads **10** and **20** are of the identical configuration and each comprises a laser generating element **11,21** driven by a common oscillator **50** through an amplifier **12,22** to generate a laser be-am which is directed through a projector lens **13,23** to an object's surface, a semi-conductor position sensing device [PSD] **14,24** receiving a laser beam reflected from the object surface through a collector lens **15,25**. As shown in FIG. 2, PSD **14,24** has an elongated light receiving surface with a pair of terminals $\mathbf{T_1}$ and $\mathbf{T_2}$ at the opposite lengthwise ends thereof and is characterized to develop currents I_1 and I_2 at the terminals $\mathbf{T_1}$ and $\mathbf{T_2}$ of which values vary depending upon a point of receiving the light. These currents I_1 and I_2 are fed through individual amplifiers $\mathbf{16_1}$ and $\mathbf{16_2}$, $\mathbf{26_1}$ and $\mathbf{26_2}$ as outputs of the first and second optical heads **10** and **20**. The center of PSD is aligned with an optical axis of the collector lens **15,25** so that a displacement ΔX of the receiving point from the center can be obtained from the following relation:

$$\Delta X = \frac{(I_1 - I_2)}{(I_1 + I_2)} \times \frac{L}{2}$$

wherein L is an effective length of the light receiving surface of PSD.

Taking into account for somewhat non-linear characteristic of PSD, the displacement can be obtained more precisely by the following relation:

$$\Delta X = \frac{(I_1 - I_2)}{(I_1 + kI_2)} \times \frac{L}{2} \quad (1)$$

wherein k is a constant selected to compensate for the non linearity.

Turning back to FIG. 1, each of the optical heads **10** and **20** is disposed with an optical axis of the projector lens **13,23** perpendicular to the object surface and with an optical axis of the collector lens **15,25** inclined at an angle of Θ with respect to the perpendicular axis. The center of the collector lens **13,23** is spaced along the perpendicular axis by a fixed distance Rc from a reference point or the point at which the two optical axes cross at an angle of Θ. The reference points of the two optical

heads **10** and **20** therefore define the reference plane PL_{ref} perpendicular to the axis of the projecting laser beam and is parallel to a general plane of the object surface. The PSD **14,24** in each head is disposed with its photo-sensitive surface perpendicular to the optical axis of the collector lens **15,25** and spaced from the center of the lens by a focal length f thereof. When the laser beam from the optical head is reflected at a point on the object's surface spaced from the reference point or plane PL_{ref} by a distance d along the perpendicular optical axis, the reflected laser beam will impinge on the surface of PSD at a point offset from the longitudinal center of PSD by a displacement of ΔX. From this geometrical relationship, the positioning of the object surface can be effected by triangulation through the following equation:

$$\Delta X = \frac{d \cdot f \cdot \tan\theta}{\frac{Rc}{\cos^2\theta} + d} \qquad (2)$$

Therefore, combining this equation (2) with the above equation (1) can give the distance d of the points on the object surface from the reference plane PL_{ref} by incorporating the outputs I_1 and I_2 of the PSD. Such arithmetic operations are made at the processing circuit **40**.

The laser beam generated at the first and second optical heads **10** and **20** is modulated by a pulse signal from the oscillator **50** such that each optical head receives modulated laser beam reflected from the object's surface and issues corresponding modulated outputs I_1 and I_2 therefrom. The outputs I_1 and I_2 are demodulated in the processing circuit **40** to give corresponding values which are free from background illumination on the object surface and therefore give reliable data for measurement of the distance D_1 and D_2. The pulse signal from the oscillator **50** is controlled by a switch controller **30** to be fed through a switch **32** alternately to the first and second optical heads **10** and **20** such that the optical heads **10** and **20** are enabled alternately. The switch controller **30** also controls the switch **31** for feeding the outputs from the first and second optical heads **10** and **20** alternately to the processing circuit **40**. The processing circuit **40**, oscillator **50**, switch controller **30**, and switches **31** and **32** are assembled into a housing (not shown) and the optical heads **10** and **20** are connected to the housing through individual cables leading to the switches **31** and **32**.

The processing circuit **40** comprises a pair of amplifiers $\mathbf{41_1}$, $\mathbf{41_2}$, demodulators $\mathbf{42_1}$, $\mathbf{42_2}$, and analog-to-digital [A/D] converter $\mathbf{43_1}$, $\mathbf{43_2}$, in addition to a CPU **44**, a digital-to-analog [D/A] converter **45**, and memories **46** and **47**. The outputs I_1 and I_2 from either of the optical heads **10** or **20** are amplified and converted at the amplifiers $\mathbf{41_1}$, $\mathbf{41_2}$ into corresponding voltages which are then demodulated at $\mathbf{42_1}$, $\mathbf{42_2}$ to provide analog signals indicative of the position of the object surface free from being influenced by the background illumination. The analog signals are converted at the A/D converters $\mathbf{43_1}$, $\mathbf{43_2}$ into digital signals for arithmetic operation at the CPU **44** to measure the perpendicular distances D_1 and D_2 of the object surface form the reference plane PL_{ref} in the manner as discussed hereinbefore. CPU **44** provides an output indicative of the measurement result which is converted at D/A converter **45** into analog signal for analog indication at an exterior display or processing at another device connected to the processing circuit. The above operation is illustrated in FIG. 3, composed of FIGS. 3A to 3G, in which the outputs I_1 and I_2 of the first optical head **10** is shown as a position current I_A while the I_1 and I_2 of the second optical head **20** is shown as a like position current I_B (FIG. 3B). The current I_A and I_B are sequentially processed into digital signals S_{A0} and S_{B0}, S_{A1} and S_{B1} .... (FIG. 3C) in synchronism with a switch control signal SW_C (FIG. 3A) which effects the changeover of the switches **31** and **32** to alternately activate the optical heads **10** and **20** and process the output from the corresponding one of the heads **10** and **20**. Digital signals S_{A0}, S_{A1}, ... and S_{B0}, S_{B1}, ... are stored respectively into memories **46** and **47** (FIGS. 3D and 3E), and are then processed at CPU **44** to provide outputs or measurement results D_0, D_1, D_2 ... (FIG. 3F). The CPU's outputs are thereafter converted at D/A converter into continuous analog signals (FIG. 3G). In this manner, the measurement is made continuously while the processing circuit **40** receives the outputs of the first and second optical heads **10** and **20**, alternately.

The CPU 44 is programmed to enable a calibration which compensate for any variations in characteristics of the electrical components used in the processing circuit **40** as well as possible misalignment between the two optical heads **10** and **20**. That is, the calibration is made by the use of an optical flat plane to measure two points on the optical flat plane such that the system gives zero difference between the measured distances D_1 and D_2 by incorporating an offset value which is stored in one of the memories **46** and **47** or another memory and is subsequently utilized for providing a correct measurement.

Second embodiment <FIG. 5>

FIG. 5 illustrates a like optical measurement system in accordance with a second embodiment of the present invention which is identical in configuration and operation to those of the first embodiment except that a pair of first and second oscillators **51** and **52** are included in the system for generating at the first and second optical heads **10A** and **20A** modulate laser beams of different oscillating frequencies in order to avoid interference between the laser beams from the first and second optical heads. In this embodiment, the first and second optical heads **10A** and **20A** are kept activated continuously as opposed to the first embodiment where they are alternately activated. With the inclusion of the two oscillators **51** and **52**, a switch controller **30A** is configured to operate demodulators $\mathbf{42_1A}$ and $\mathbf{42_2A}$ at the corresponding frequencies by means of a switch **33**, in addition to

alternately transmitting the outputs from the first and second optical heads **10A** and **20A** to a processing unit **40A** through a switch **31A**. Like parts or elements are designated by like numerals with a suffix letter of "A".

Third embodiment <FIGS. 6 to 9>

FIG. 6 illustrates a like optical measurement system in accordance with a third embodiment of the present invention which is identical in configuration and operation to the first embodiment except that a pair of sample-and-hold (S/H) circuits 48_1 and 48_2 is included in a processing circuit **40B** in place of the demodulators in the first embodiment. Also included in the processing circuit **40B** in association with the S/H circuits is a timing circuit **55** which generates timed pluses LP, SH, and CN based upon the oscillating frequency of the oscillator **50B**. Pulses LP are fed alternately to the first and second optical heads **10B** and **20B** through a switch **32B** to generate the pulse modulated laser beam of a given frequency, as shown in FIG. 7A. The resulting laser beams are each characterized to have high and low levels such that each of the first and second optical heads **10B** and **20B** provides correspondingly high and low level values for each of the outputs I_1 and I_2 from the opposite ends of PSD **14B** within one cycle T of the pulses D_1. Pulses SH are fed to the S/H circuits 48_1 and 48_2 in order to sample and hold the high level value for each of the outputs I_1 and I_2 within a half cycle (T/2) of the laser beam generating pulses LP and subsequently sample and hold the low level value for the same within the other half cycle of the pulses LP, as shown in FIG. 7B. In this manner, the high level and low level values within one pulse of the reflected laser beam from the object's surface to the PSD are taken and then converted at individual A/D converters 43_1**B** and 43_2**B** into corresponding high and low digital values V_H and V_L under the control of the pulses CN fed to the A/D converters as control pulses, as shown in FIG. 7C. Thus obtained digital values are processed at the CPU **44B** to provide a difference value V_{def} between the high and low level values ($V_{def} = V_H - V_L$) within one cycle of the laser beam received at the PSD for each of the outputs I_1 and I_2 from each one of the optical heads **10B** and **20B**. This subtraction can therefore cancel any variations in characteristics of the electrical components in the circuit as well as the background illumination because of that such variations will appear equally in the high and low level values and can be therefore eliminated in the difference value ($V_{def} = V_H - V_L$). This is more apparent when considering the followings with reference to FIGS. 8A and 8B which illustrate exemplarily the waveform of the laser beam received at the PSD and the waveform in solid line of the output of the amplifiers 41_1**B** or 41_2**B**. The output of the amplifier gives high and low level values V_H and V_L which includes true values V_{HT} and V_{LT} (shown in dotted waveform in FIG. 8B) plus the variations var of the same extent, as expressed in the below.

$$V_H = V_{HT} + \mathrm{var}$$

$$V_L = V_{LT} + \mathrm{var}$$

Therefore, subtraction of V_H and V_L will cancel the variations and results in the difference between the true values (V_{HT}-V_{LT}). In this manner, the system can extract from the outputs I_1 and I_2 of the PSD of each optical head reliable and true data indicative of the position of the object surface and is therefore capable of reliably measuring the distances of the individual points on the object's surface from the reference plane PL_{ref} for accurate determination of the depth D of the step in the object surface.

The system additionally includes error-free capability of invalidating the measurement when the high level value V_H or low level value V_L goes beyond an allowable range R of the A/D converter 43_1**B** or 43_2**B**. For example, as shown in FIG. 9A and 9B, when the level of the laser beam received at the PSD increases remarkably, as shown in FIG. 9A, due to, for example, an abrupt increase in reflectance of the object's surface, an overshooting will occur in the output of the S/H circuit such that the A/D converter 43_1**B** receives abnormally increased high level output beyond the allowable range R for a while, as indicated by a time interval of T_1 in FIG. 9B, until the correct level output is reached. During that interval, A/D converter will generate a maximum level value although it does not actually indicate the intensity of the laser beam received at the PSD and would therefore result in erroneous measurement at CPU. However, such erroneous measurement can be avoided by the above arrangement which is applied to both of the outputs I_1 and I_2 of the PSD for each of the optical heads **10B** and **20B**.

Fourth embodiment <FIGS. 10 and 11>

FIG. 10 illustrates a like optical measurement system in accordance with a fourth embodiment of the present invention which is basically identical to the first embodiment except that a supervising section **60** is included in a processing circuit **40C** for checking whether first and second optical heads **10C** and **20C** are correctly coupled to corresponding connectors C_1 and C_2 of the processing circuit **40C**. Like elements and components are designated by like numerals with a suffix letter of "C". The connectors C_1 and C_2 are provided on a housing incorporating the processing circuit **40C** together with the supervising section **60**, an oscillator **50C**, a switch controller **30C**, and the switch **31C**. For reason of that there may be some variation in output characteristic of the separate heads **10C** and **20C**, the calibration is made in the system to compensate for that variation in order to give consistent measurement. That is, the processing circuit **40C** is given suitable compensation at the calibration which is stored in the memory and is utilized in measurement of the individual distances of the

points on the object's surface from the outputs of the separate heads **10C** and **20C**. Such compensation can be effective provided that the two optical heads **10C** and **20C** are correctly coupled to the connectors C_1 and C_2 of the processing circuit **40C**. The correct connection is checked at the supervising section **60** for providing consistent measurements. As shown in FIG. 11, the supervising section **60** comprises a pair of first and second comparators **61** and **62** and a switch **63** which is controlled by CPU of the processing circuit to transmit in sequence different voltage signals V_1 and V_2 for the individual heads **10C** and **20C** through the connectors C_1 and C_2. The voltage signals V_1 and V_2 are issued from address signal generators 17_1 and 17_2, respectively included in the optical heads **10C** and **20C**. In this instance, the voltage signal V_1 for the first head **10C** is obtained from a fixed voltage V through a resistor R_1, while the voltage signal V_2 is obtained directly from the fixed voltage V. A resistor **R2** is connected commonly to (+) inputs of the comparators **61** and **62** so that the first and second comparators **61** and **62** receive at their (+) inputs the voltage $V_{in} = V \times R_2/(R_1+R_2)$ and $V_{in} = V$, respectively when the first and second optical heads **10C** and **20C** are coupled correctly to the connectors C_1 and C_2, respectively. The first and second comparators **61** and **62** have reference voltages V_{ref1} and V_{ref2} ($V_{ref1} < V_{ref2}$) so that the first comparator **61** outputs a H-level signal when the input voltage V_{in} exceeds the reference voltage V_{ref1} and outputs a L-level signal otherwise, and the second comparator **62** outputs a H-level signal when the input voltage V_{in} exceeds the reference voltage V_{ref2} and a L-level signal otherwise. The outputs of the first and second comparators **61** and **62** are fed to the CPU of the processing circuit **40C** where they are analyzed to judge whether the heads **10C** and **20C** are correctly coupled to the associated connectors C_1 and C_2. When, for example, the first comparator **61** outputs the H-level signal as indicative of that the either of the head **10C** or **20C** is coupled to the connector C_1, then the CPU checks whether the output of the second comparator **62** and judges that the heads **10C** and **20C** are correctly coupled to the associated terminals C_1 and C_2, respectively when the second comparator **62** outputs the H-level signal, and that the heads **10C** and **20C** are mis-coupled to the terminals C_1 and C_2, respectively or even no connection is made to the terminal C_2 when the second comparator **62** outputs the L-level signal. Further, when the first comparator **61** outputs the L-level signal, the CPU acknowledges that at least the terminal C_1 is not connected to any one of the heads. When the non-connection or mis-connection is judged, the system responds to disable the measurement and produces a warning signal urging the user to reconnect the heads to the correct terminals. Instead of using the voltage signals differentiated by the use of the resistor R_1, it is equally possible to provide coded signals from the individual heads so that the processing circuit can acknowledge the heads by analysis of the coded signals.

It should be noted that the present invention should not be limited to the two-head measurement system and may includes three or more optical heads for analyzing the object's surface in view of three or more points on the object's surface. In such modification also, the single processing circuit is responsible for measurement of the individual distances or positions of these points from the outputs of the individual optical heads.

Claims

1. An optical measurement system for determination of the depth of a step in a profile of an object, said system comprising:

   a first optical head (10) including light projector means (11,12,13) for directing a first light beam on to a first point on a surface of the object and including photo-sensor means (14) arranged to receive reflected light from said first point on the surface, and to provide a first output which varies in proportion to the perpendicular distance (D1) from a reference plane (PLref) to said first point on the object's surface;
   a second optical head (20) including light projector means (21, 22, 23) for directing a second light beam on.to a second point on said surface of the object, and including photo-sensor means (24) arranged to receive reflected light from said second point on the surface, and to provide a second output which varies in proportion to the perpendicular distance (D2) from a reference plane (PLref) to said second point on the object's surface; and
   circuitry for analysing the surface of the object based upon said first and second outputs, said system being characterised in further comprising:
   switch means (31) for selectively connecting said first and second outputs to a single processing circuit (40), said single processing circuit (40) being operable to process said first and second outputs in sequence to measure by triangulation the perpendicular distances (D1, D2) of said first and second points from said reference plane (PLref), and to subtract the perpendicular distances (D1, D2) thereby to determine the depth of the step in the profile of the object.

2. An optical measurement system as set forth in claim 1, wherein said first and second optical heads (10, 20) are controlled to project in sequence said first and second pulse modulated light beams (I_1, I_2), said processing circuit (40) including demodulator means (42_1, 42_2) effective to demodulate said first and second outputs (I_1, I_2) and means for process-

ing the resulting demodulated signals in order to measure said perpendicular distances (D1, D2).

3. An optical measurement system as set forth in claim 1, wherein said first and second optical heads (10A, 20A) are arranged to project first and second light beams which are pulse modulated to have different oscillating frequencies from each other, said processing circuit (40A) including demodulator means (42_1A, 42_2A) effective to demodulate said first and second outputs in order to enable processing of the resulting demodulated signals so as to measure said perpendicular distances (D1, D2).

4. An optical measurement system as set forth in claim 1, wherein said processing circuit (40) includes calibration means which compensates for variations in said perpendicular distances (D1, D2) measured respectively with respect to said first and second outputs from said first and second optical heads (10B, 20B) when directing said first and second light beams to said first and second points selected on an optical flat plane parallel to said reference plane (PLref).

5. An optical measurement system as set forth in claim 1 or 4, further including means for adjusting the spacing between the optical axes of said first and second light beams along a direction perpendicular to said optical axes.

6. An optical measurement system as set forth in claim 1, wherein said first and second light beams are modulated, each beam comprising alternating high and low levels so that said first and second optical heads (10B, 20B or 10C, 20C) produce high level and low level values with respect to each of said first and second outputs, said processing circuit (40B or 40C) including level detection means for calculating a difference between said high and low level values for each of said first and second outputs and for using said difference as a true value for each of said first and second outputs in order to measure said first and second perpendicular distances (D1, D2).

7. An optical measurement system as set forth in claim 6, wherein said level detection means comprises a sample-and-hold circuit (48_1, 48_2) which operates in synchronism with said pulse modulated first and second light beams so as to obtain said high and low level values for each of said first and second outputs.

8. An optical measurement system as set forth in claim 6, wherein said processing circuit (40C) includes error detecting means (61, 62) which invalidates the measurement of said first and second distances when said high level value exceeds a predetermined maximum level or said low level value falls below a predetermined minimum level.

9. An optical measurement method for determination of the depth of a step in a profile of an object, said method using:

a first optical head (10) including light projector means (11, 12, 13) directing a first light beam to a first point on a surface of the object and including photo-sensor means (14) receiving a reflected light from said first point on the surface and providing a first output which varies in proportion to a perpendicular distance (D1) from a reference plane (PLref) to said first point on the object's surface;
a second optical head (20) including light projector means (21, 22, 23) directing a second light beam to a second point on said surface of the object and including photo-sensor means (24) receiving a reflected light from said second point on the surface and providing a second output which varies in proportion to a perpendicular distance from a reference plane to said second point on the object's surface;

said method being characterised by the use of:

a single processing circuit (40) capable of processing said first and second outputs to measure by triangulation the perpendicular distances (D1, D2) of said first and second points respectively from said reference plane (PLref) and analysing a surface of the object based upon thus measured perpendicular distances (D1, D2),
said method comprising delivering said first output from said first optical head (10) to said common processing circuit (40) for determination of said first perpendicular distance (D1) and then delivering said second output from said second optical head (20) to said common processing circuit (40) for determination of said second perpendicular distance (D2), and subtracting said first and second perpendicular distances (D1, D2) thereby to determine the depth of the step in the profile of the object.

Patentansprüche

1. Optisches Meßsystem zum Ermitteln der Tiefe einer Stufe im Profil eines Gegenstands, das folgendes aufweist:

- einen ersten optischen Kopf (10) mit einer Lichtprojiziereinrichtung (11, 12, 13) zum Lenken eines ersten Lichtstrahls auf einen ersten Punkt auf einer Oberfläche des Gegenstands, und mit

einer Lichtsensoreinrichtung (14), die so angeordnet ist, daß sie vom ersten Punkt auf der Oberfläche reflektiertes Licht empfängt, um ein erstes Ausgangssignal zu erzeugen, das sich proportional zum rechtwinkligen Abstand (D1) des ersten Punkts auf der Gegenstandsoberfläche von einer Bezugsebene (PLref) ändert;

- einen zweiten optischen Kopf (20) mit einer Lichtprojiziereinrichtung (21, 22, 23) zum Lenken eines zweiten Lichtstrahls auf einen zweiten Punkt auf einer Oberfläche des Gegenstands, und mit einer Lichtsensoreinrichtung (24), die so angeordnet ist, daß sie vom zweiten Punkt auf der Oberfläche reflektiertes Licht empfängt, um ein zweites Ausgangssignal zu erzeugen, das sich proportional zum rechtwinkligen Abstand (D2) des zweiten Punkts auf der Gegenstandsoberfläche von der Bezugsebene (PLref) ändert;
- eine Schaltung zum Analysieren der Gegenstandsoberfläche auf Grundlage des ersten und zweiten Ausgangssignals;

wobei das System durch folgendes **gekennzeichnet** ist:

- eine Umschalteinrichtung (31) zum selektiven Verbinden des ersten und zweiten Ausgangssignals mit einer einzelnen Verarbeitungsschaltung (40), die so betreibbar ist, daß sie das erste und zweite Ausgangssignal aufeinanderfolgend mittels einer Triangulation der rechtwinkligen Abstände (D1, D2) des ersten und zweiten Punkts von der Bezugsebene (PLref) mißt und sie die rechtwinkligen Abstände (D1, D2) subtrahiert, um dadurch die Tiefe der Stufe im Profil des Gegenstands zu ermitteln.

2. Optisches Meßsystem nach Anspruch 1, bei dem der erste und zweite optische Kopf (10, 20) so gesteuert werden, daß sie den ersten und zweiten impulsmodulierten Lichtstrahl (l_1, l_2) aufeinanderfolgend abstrahlen, wobei die Verarbeitungsschaltung (40) eine Demodulatoreinrichtung (42_1, 42_2), die so arbeitet, daß sie das erste und zweite Ausgangssignal (l_1, l_2) demoduliert, und eine Einrichtung zum Verarbeiten der sich ergebenden demodulierten Signale aufweist, um die rechtwinkligen Abstände (D1, D2) zu messen.

3. Optisches Meßsystem nach Anspruch 1, bei dem der erste und zweite optische Kopf (10A, 20A) so ausgebildet sind, daß sie einen ersten und einen zweiten Lichtstrahl abstrahlen, die so impulsmoduliert sind, daß sie voneinander verschiedene Schwingungsfrequenzen aufweisen, wobei die Verarbeitungsschaltung (40A) eine Demodulatoreinrichtung (42_1A, 42_2A), die so arbeitet, daß sie das erste und zweite Ausgangssignal demoduliert, und eine Einrichtung zum Verarbeiten der sich ergebenden demodulierten Signale aufweist, um die rechtwinkligen Abstände (D1, D2) zu messen.

4. Optisches Meßsystem nach Anspruch 1, bei dem die Verarbeitungsschaltung (40) eine Kalibriereinrichtung enthält, die Abweichungen zwischen den rechtwinkligen Abständen (D1, D2) wie jeweils aus dem ersten und zweiten Ausgangssignal vom ersten und zweiten optischen Kopf (10B, 20B) gemessen, kompensiert, wenn der erste und zweite Lichtstrahl auf den ersten und zweiten Punkt gerichtet werden, die auf einer optischen Ebene parallel zur Bezugsebene (PLref) ausgewählt sind.

5. Optisches Meßsystem nach einem der Ansprüche 1 oder 4, ferner mit einer Einrichtung zum Einstellen des Abstands zwischen den optischen Achsen des ersten und zweiten Lichtstrahls entlang einer Richtung rechtwinklig zu den optischen Achsen.

6. Optisches Meßsystem nach Anspruch 1, bei dem der erste und zweite Lichtstrahl moduliert werden, wobei jeder Lichtstrahl abwechselnd einen hohen und niedrigen Pegel aufweist, so daß der erste und zweite optische Kopf (10B, 20B oder 10C, 20C) Werte mit hohem Pegel und niedrigem Pegel hinsichtlich sowohl des ersten als auch zweiten Ausgangssignals erzeugen, wobei die Verarbeitungsschaltung (40B oder 40C) eine Pegelerkennungseinrichtung aufweist, um die Differenz zwischen den Werten mit hohem und niedrigem Pegel für jeweils das erste und zweite Ausgangssignal zu berechnen, und um die Differenz als richtigen Wert für das erste und zweite Ausgangssignal zu verwenden, um den ersten und zweiten rechtwinkligen Abstand (D1, D2) zu messen.

7. Optisches Meßsystem nach Anspruch 6, bei dem die Pegelerfassungseinrichtung eine Abtast/Halte-Schaltung (48_1, 48_2) umfaßt, die synchron mit dem impulsmodulierten ersten und zweiten Lichtstrahl arbeitet, um Werte mit hohem und niedrigem Pegel sowohl für das erste als auch zweite Ausgangssignal zu erhalten.

8. Optisches Meßsystem nach Anspruch 6, bei dem die Verarbeitungsschaltung (40C) eine Fehlererkennungseinrichtung (61, 62) aufweist, die die Messung des ersten und zweiten Abstands ungültig macht, wenn der Wert mit hohem Pegel einen vorgegebenen maximalen Pegel übersteigt oder wenn der Wert mit niedrigem Pegel unter einen vorgegebenen Minimalpegel fällt.

9. Optisches Meßverfahren zum Ermitteln der Tiefe einer Stufe im Profil eines Gegenstands, das folgen-

des aufweist:

- einen ersten optischen Kopf (10) mit einer Lichtprojiziereinrichtung (11, 12, 13) zum Lenken eines ersten Lichtstrahls auf einen ersten Punkt auf einer Oberfläche des Gegenstands, und mit einer Lichtsensoreinrichtung (14), die so angeordnet ist, daß sie vom ersten Punkt auf der Oberfläche reflektiertes Licht empfängt, um ein erstes Ausgangssignal zu erzeugen, das sich proportional zum rechtwinkligen Abstand (D1) des ersten Punkts auf der Gegenstandsoberfläche von einer Bezugsebene (PLref) ändert;
- einen zweiten optischen Kopf (20) mit einer Lichtprojiziereinrichtung (21, 22, 23) zum Lenken eines zweiten Lichtstrahls auf einen zweiten Punkt auf einer Oberfläche des Gegenstands, und mit einer Lichtsensoreinrichtung (24), die so angeordnet ist, daß sie vom zweiten Punkt auf der Oberfläche reflektiertes Licht empfängt, um ein zweites Ausgangssignal zu erzeugen, das sich proportional zum rechtwinkligen Abstand des zweiten Punkts auf der Gegenstandsoberfläche von der Bezugsebene ändert;

wobei das Verfahren durch die Verwendung von folgendem **gekennzeichnet** ist:

- einer einzelnen Verarbeitungsschaltung (40), die das erste und zweite Ausgangssignal verarbeiten kann, um durch Triangulation die rechtwinkligen Abstände (D1, D2) des ersten und zweiten Punkts jeweils von der Bezugsebene (PLref) zu messen und eine Oberfläche des Gegenstands auf Grundlage der so gemessenen rechtwinkligen Abstände (D1, D2) zu analysieren;
- wobei das Verfahren folgendes umfaßt: Ausgeben des ersten Ausgangssignals vom ersten optischen Kopf (10) an die gemeinsame Verarbeitungsschaltung (40), um den ersten rechtwinkligen Abstand (D1) zu ermitteln, und anschließendes Ausgeben des zweiten Ausgangssignals vom zweiten optischen Kopf (20) an die gemeinsame Verarbeitungsschaltung (40), um den zweiten rechtwinkligen Abstand (D2) zu ermitteln, und Subtrahieren des ersten und zweiten rechtwinkligen Abstands (D1, D2), um dadurch die Tiefe der Stufe im Profil des Gegenstands zu ermitteln.

Revendications

1. Système de mesure optique pour la détermination de la profondeur d'un pas dans le profil d'un objet, ledit système comprenant:

- une première tête optique (10) avec des moyens de projection de lumière (11, 12, 13) pour diriger un premier faisceau de lumière vers un premier point sur la surface de l'objet et comprenant des moyens capteurs lumineux (14) susceptibles de recevoir la lumière réfléchie en provenance dudit premier point sur la surface, et de fournir un premier signal de sortie qui varie en proportion de la distance (D_1) entre ledit premier point sur la surface de l'objet et un plan de référence (PL_{ref});
- une seconde tête optique (20) avec des moyens de projection de lumière (21, 22, 23) pour diriger un second faisceau de lumière vers un second point sur la surface de l'objet et comprenant des moyens capteurs lumineux (24) susceptibles de recevoir la lumière réfléchie en provenance dudit second point sur la surface, et de fournir un second signal de sortie qui varie en proportion de la distance (D_2) entre ledit second point sur la surface de l'objet et un plan de référence (PL_{ref}); et
- des circuits d'analyse de la surface de l'objet en fonction desdits premier et second signaux de sortie;

ledit système étant caractérisé en ce qu'il comprend en outre:

- des moyens de commutation (31) pour relier sélectivement lesdits premier et second signaux de sortie à un circuit de traitement unique (40), ledit circuit de traitement unique (40) étant susceptible de fonctionner pour traiter lesdits premier et second signaux de sortie en série pour mesurer par triangulation les distances (D_1, D_2) entre lesdits premier et second points et ledit plan de référence (PL_{ref}), et pour soustraire les distances (D_1, D_2) afin de déterminer la profondeur du pas dans le profil de l'objet.

2. Système de mesure optique selon la revendication 1, dans lequel lesdites première et seconde têtes optiques (10, 20) sont commandées pour projeter en série lesdits premier et second faisceaux lumineux modulés en impulsions (I_1, I_2), ledit circuit de traitement (40) comprenant des moyens de démodulation (42_1, 42_2) susceptibles de démoduler lesdits premier et second signaux de sortie (I_1 et I_2) et des moyens de traitement des signaux démodulés résultants pour la mesure desdites distances (D_1, D_2).

3. Système de mesure optique selon la revendication 1, dans lequel lesdites première et seconde têtes optiques (10A, 20A) sont disposées de sorte à projeter des premier et second faisceaux lumineux qui sont modulés en impulsions pour présenter des fré-

quences d'oscillations différentes l'une de l'autre, ledit circuit de traitement (40A) comprenant des moyens de démodulations (42_1A, 42_2A) susceptibles de démoduler lesdits premier et second signaux de sortie afin de permettre un traitement des signaux démodulés résultants pour mesurer desdites distances (D_1, D_2).

4. Système de mesure optique selon la revendication 1, dans lequel ledit circuit de traitement (40) comprend des moyens d'étalonnage qui compensent les variations dans lesdites distances (D_1, D_2) mesurées respectivement à partir desdits premier et second signaux de sortie en provenance des première et seconde têtes optiques (10B, 20B) lorsque l'on dirige lesdits premier et second faisceaux lumineux vers lesdits premier et second points choisis sur un plan optique plat parallèle audit plan de référence (PL_{ref}).

5. Système de mesure optique selon la revendication 1 ou 4, comprenant en outre des moyens de réglage de la distance entre les axes optiques desdits premier et second faisceaux lumineux le long d'une direction perpendiculaire auxdits axes optiques.

6. Système de mesure optique selon la revendication 1, dans lequel lesdits premier et second faisceaux lumineux sont modulés, chaque faisceau comprenant des niveaux haut et bas alternés, de telle sorte que lesdites première et seconde têtes optiques (10B, 20B ou 10C, 20C) produisent des valeurs de niveau haut et de niveau bas sur chacun desdits premier et second signaux de sortie, ledit circuit de traitement (40B ou 40C) comprenant des moyens de détection de niveau pour calculer la différence entre lesdites valeurs de niveau haut et de niveau bas pour chacun desdits premier et second signaux de sortie, et pour utiliser cette différence en tant que valeur réelle pour chacun desdits premier et second signaux de sortie afin de mesurer lesdites première et seconde distances (D_1, D_2).

7. Système de mesure optique selon la revendication 6, dans lequel lesdits moyens de détection de niveau comprennent un circuit d'échantillonnage et de maintien (48_1, 48_2) qui fonctionne de façon synchrone auxdits premier et second faisceaux lumineux modulés en impulsions, de sorte à obtenir des valeurs de niveau haut et de niveau bas pour chacun desdits premier et second signaux de sortie.

8. Système de mesure optique selon la revendication 6, dans lequel ledit circuit de traitement (40C) comprend des moyens de détection d'erreur (61, 62) qui invalident la mesure desdites première et seconde distances lorsque ladite valeur de niveau haut dépasse un niveau maximum prédéterminé ou lorsque ladite valeur de niveau bas tombe en-dessous d'un niveau minimum prédéterminé.

9. Procédé de mesure optique pour la détermination de la profondeur d'un pas dans le profil d'un objet, ledit procédé utilisant:

- une première tête optique (10) comprenant des moyens de projection de lumière (11, 12, 13) dirigeant un premier faisceau de lumière vers un premier point sur la surface de l'objet et comprenant des moyens de capteurs lumineux (14) recevant la lumière réfléchie en provenance du premier point sur la surface et fournissant un premier signal de sortie qui varie en proportion à la distance (D_1) entre ledit premier point sur la surface de l'objet et un point de référence (PL_{ref});
- une seconde tête optique (20) comprenant des moyens de projection de lumière (21, 22, 23) dirigeant un second faisceau de lumière vers un second point sur la surface de l'objet et comprenant des moyens de capteurs lumineux (24) recevant la lumière réfléchie en provenance du second point sur la surface et fournissant un second signal de sortie qui varie en proportion à la distance entre ledit second point sur la surface de l'objet et un point de référence;

ladite méthode étant caractérisée en ce qu'elle utilise:

- un circuit de traitement unique (40) susceptible de traiter lesdits premier et second signaux de sortie pour mesurer par triangulation les distances respectives (D_1, D_2) entre lesdits premier et second points et ledit plan de référence, et susceptible d'analyser la surface de l'objet en fonction des distances (D_1, D_2) ainsi mesurées;

ladite méthode comprenant la fourniture dudit premier signal de sortie en provenance de ladite première tête optique (10) audit circuit de traitement commun (40) pour déterminer ladite première distance (D_1), puis la fourniture dudit second signal de sortie en provenance de ladite seconde tête optique (20) audit circuit de traitement commun (40) pour déterminer ladite seconde distance (D_2) et la soustraction desdites première et seconde distances (D_1, D_2) afin de déterminer la profondeur du pas dans le profil de l'objet.

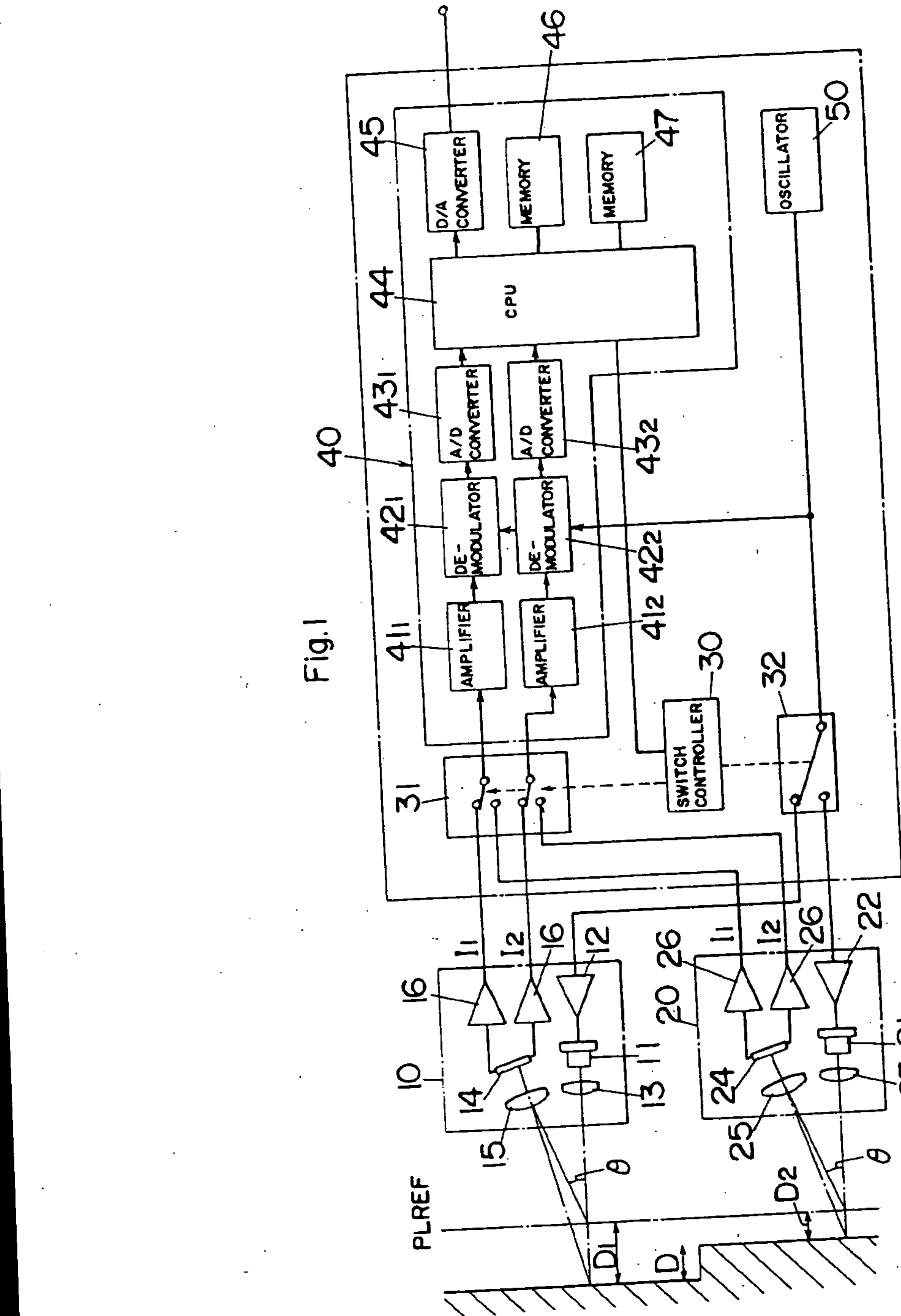
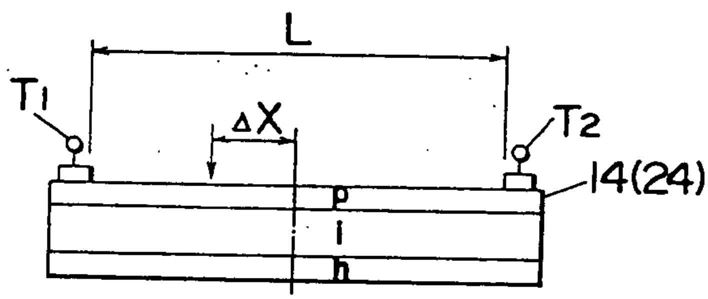

D/A CONVERTER
MEMORY
MEMORY
OSCILLATOR
CPU
A/D CONVERTER
A/D CONVERTER
DE-MODULATOR
DE-MODULATOR
AMPLIFIER
AMPLIFIER
SWITCH CONTROLLER
PLREF

Fig.1

Fig.2



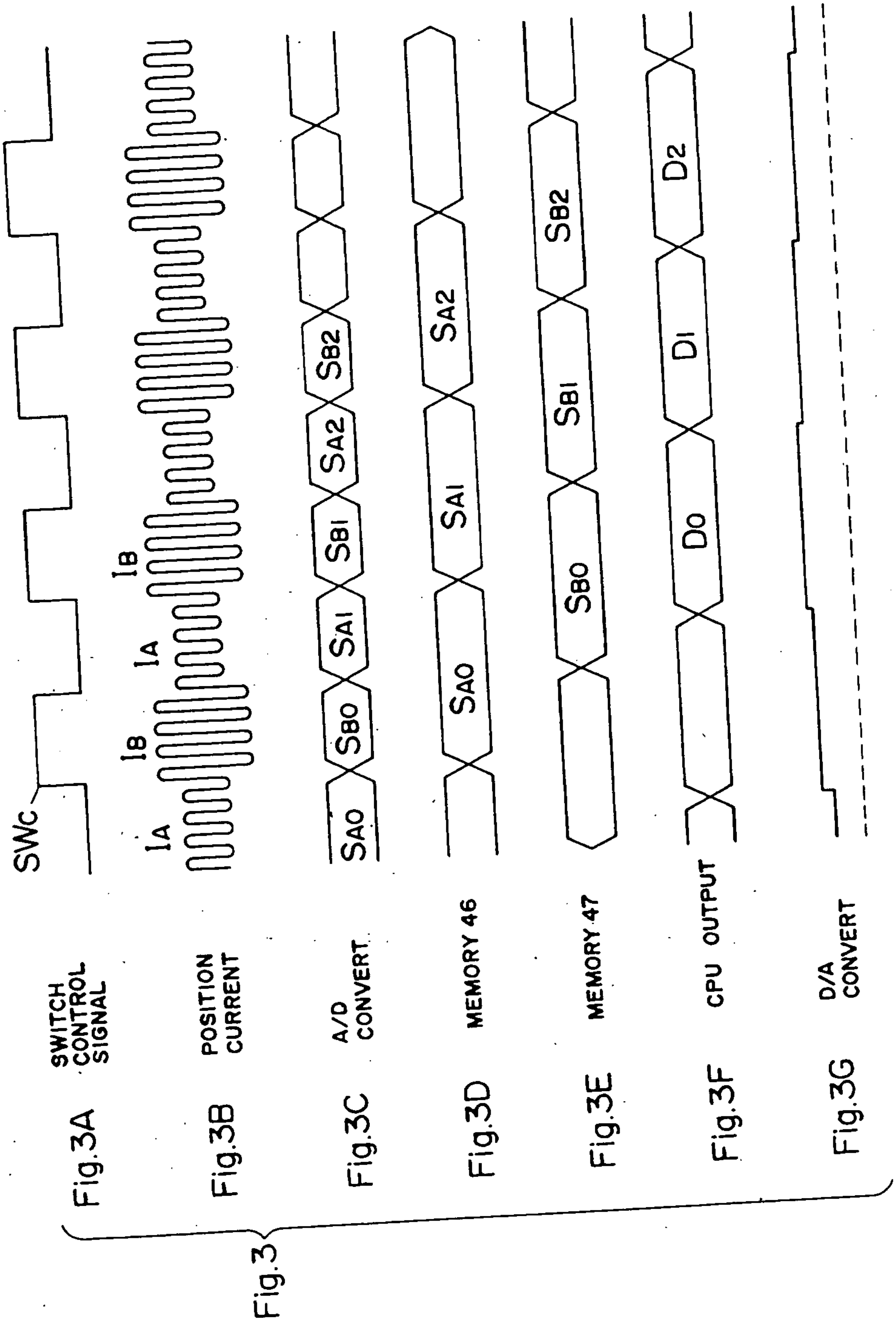
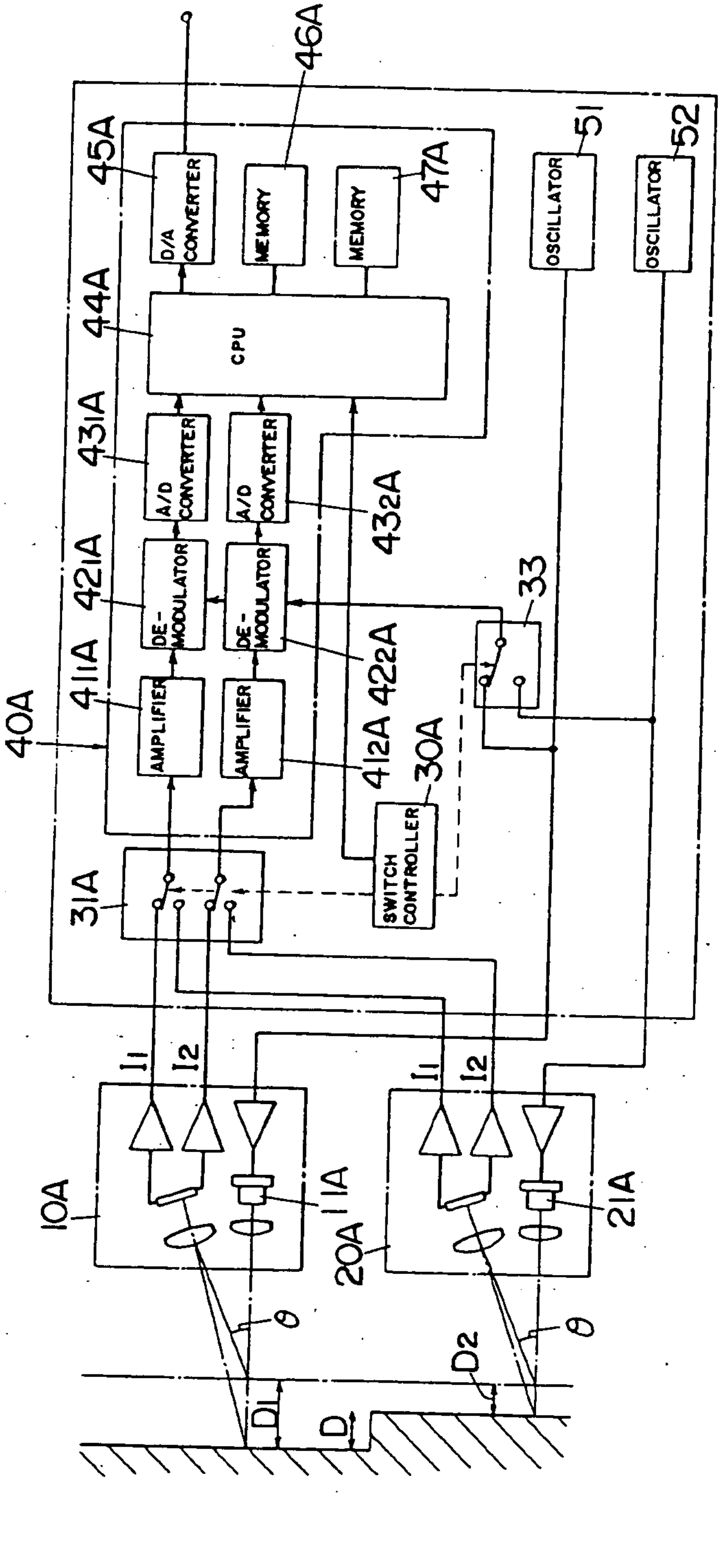


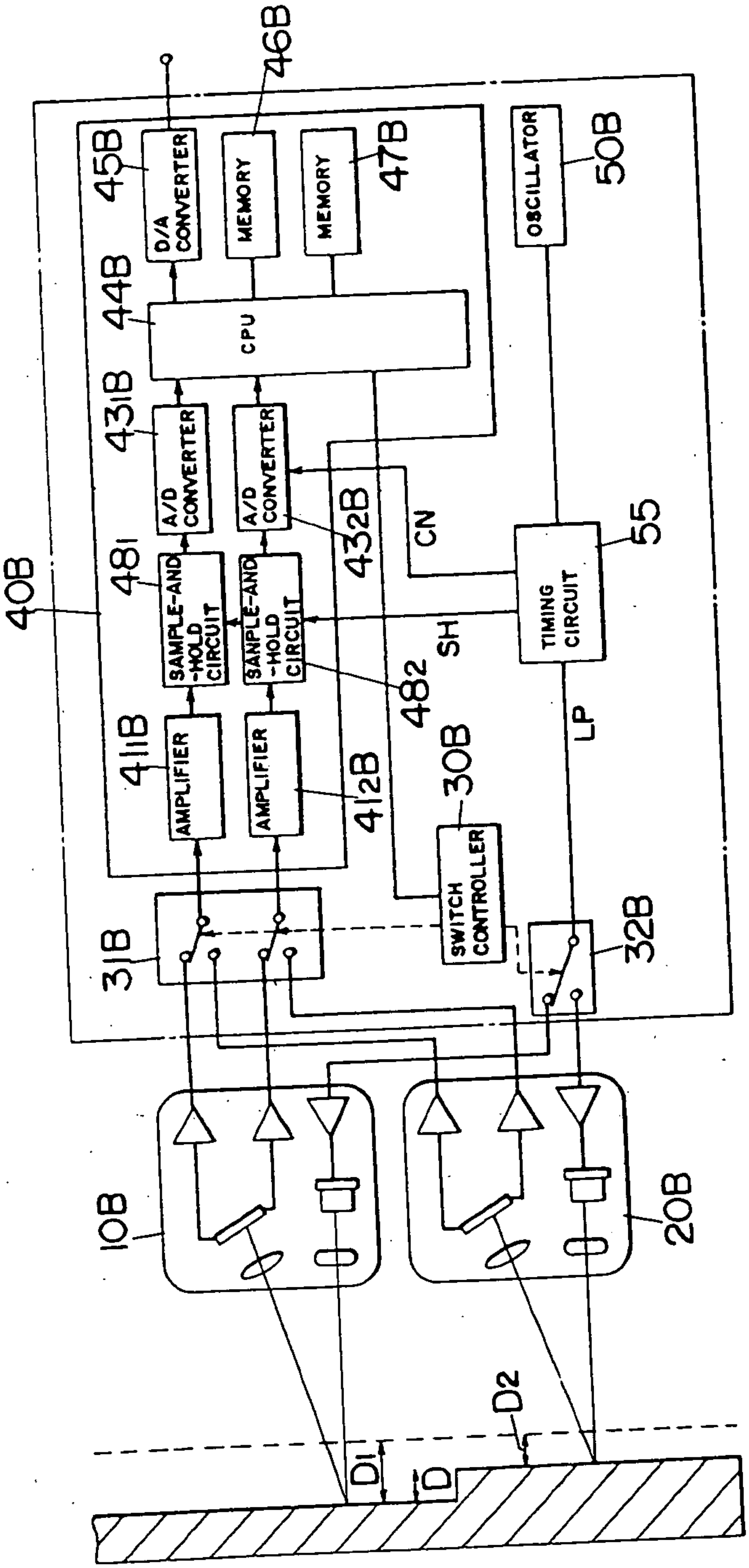
Fig.3
Fig.3A SWITCH CONTROL SIGNAL
SWc
Fig.3B POSITION CURRENT
IA
IB
IA
IB
Fig.3C A/D CONVERT
SA0
SB0
SA1
SB1
SA2
SB2
Fig.3D MEMORY 46
SA0
SA1
SA2
Fig.3E MEMORY 47
SB0
SB1
SB2
Fig.3F CPU OUTPUT
D0
D1
D2
Fig.3G D/A CONVERT

Fig.5



40A
45A
46A
47A
44A
431A
432A
421A
422A
411A
412A
30A
31A
33
51
52
10A
11A
20A
21A
D/A CONVERTER
MEMORY
MEMORY
OSCILLATOR
OSCILLATOR
CPU
A/D CONVERTER
A/D CONVERTER
DE-MODULATOR
DE-MODULATOR
AMPLIFIER
AMPLIFIER
SWITCH CONTROLLER
I1
I2
I1
I2
θ
θ
D1
D2
D

Fig.6


40B
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411B
412B
481
482
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432B
44B
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46B
47B
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30B
32B
55
10B
20B
D/A CONVERTER
MEMORY
MEMORY
CPU
A/D CONVERTER
A/D CONVERTER
SAMPLE-AND-HOLD CIRCUIT
SAMPLE-AND-HOLD CIRCUIT
AMPLIFIER
AMPLIFIER
OSCILLATOR
TIMING CIRCUIT
SWITCH CONTROLLER
CN
SH
LP
D1
D
D2

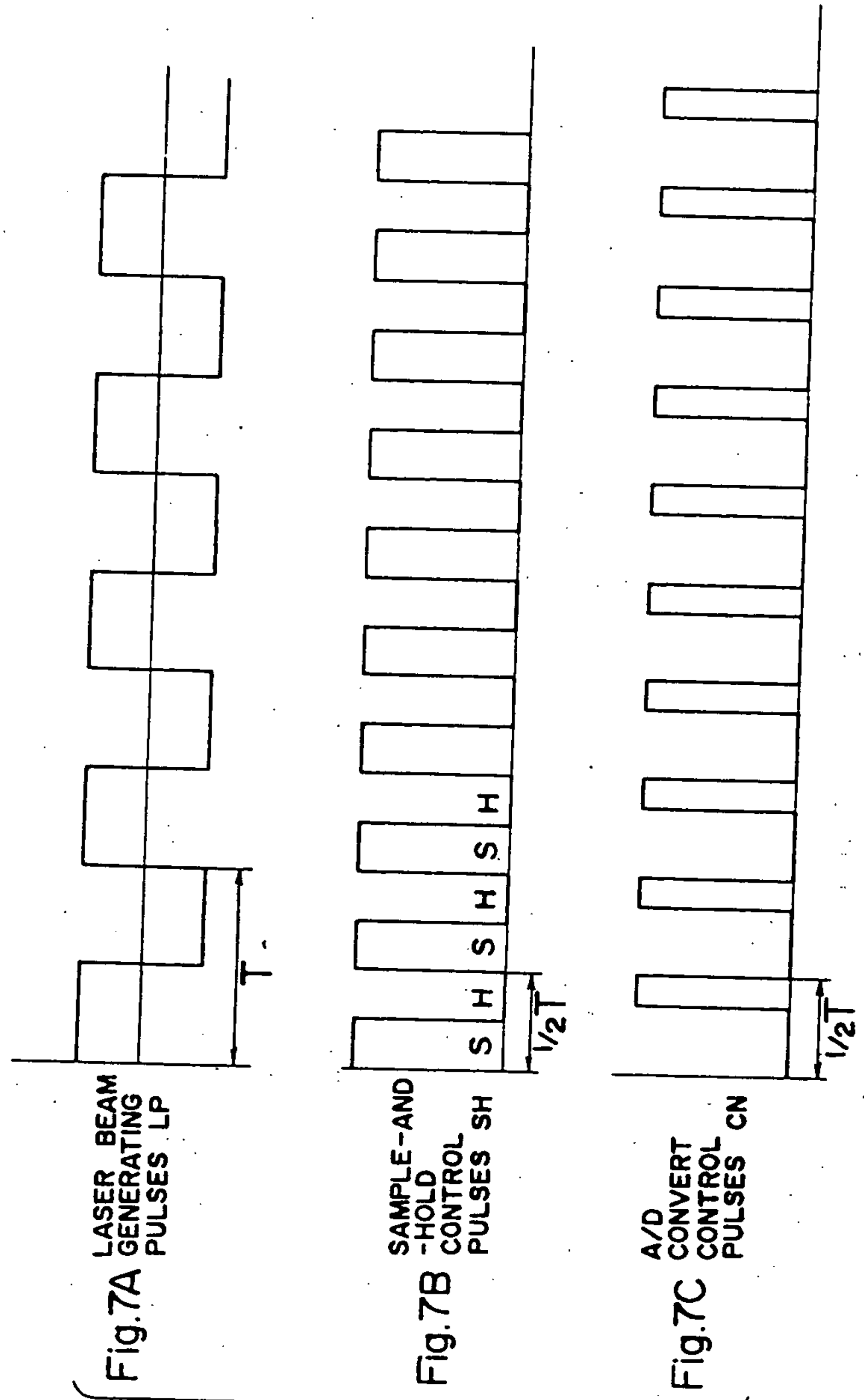


Fig.7A
LASER BEAM GENERATING PULSES LP
T
Fig.7B
SAMPLE-AND -HOLD CONTROL PULSES SH
S H S H S H
1/2T
Fig.7C
A/D CONVERT CONTROL PULSES CN
1/2T

Fig.7

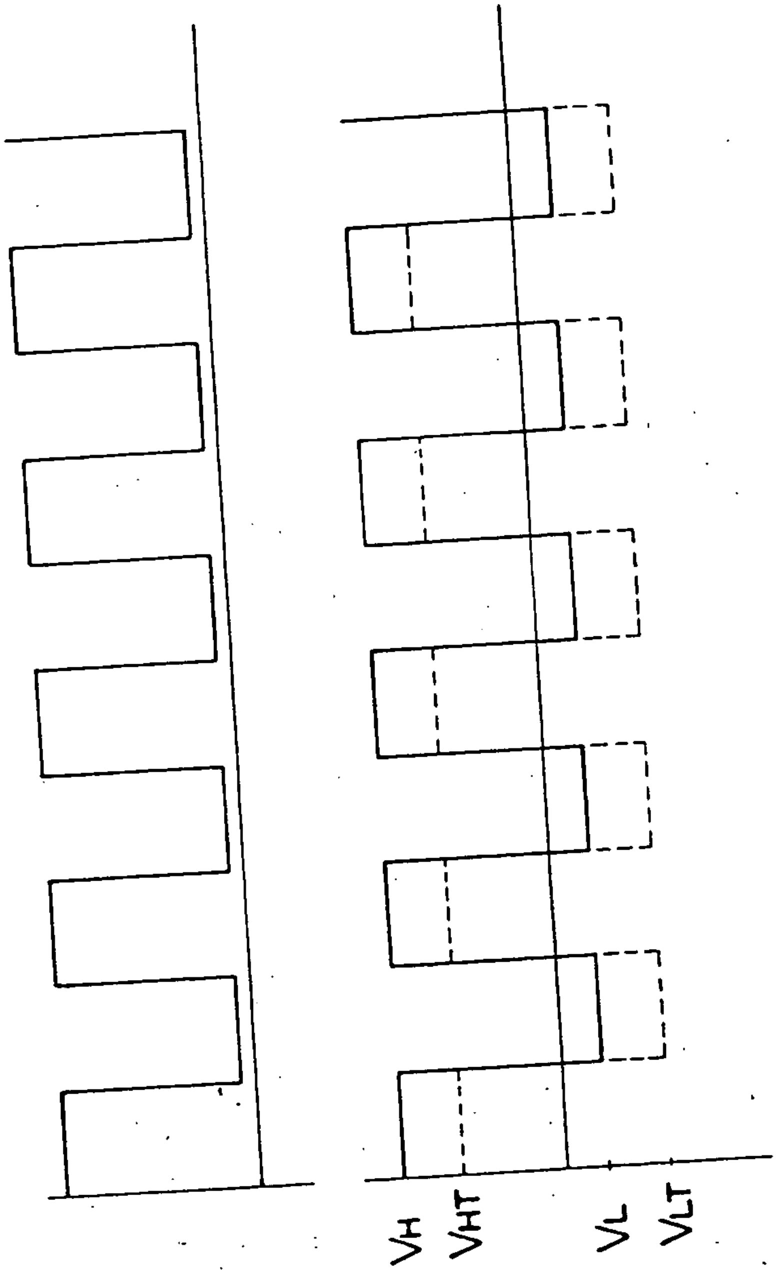


Fig.8A LASER BEAM RECEIVED AT PSD

Fig.8B AMPLIFIER OUTPUT

Fig.8

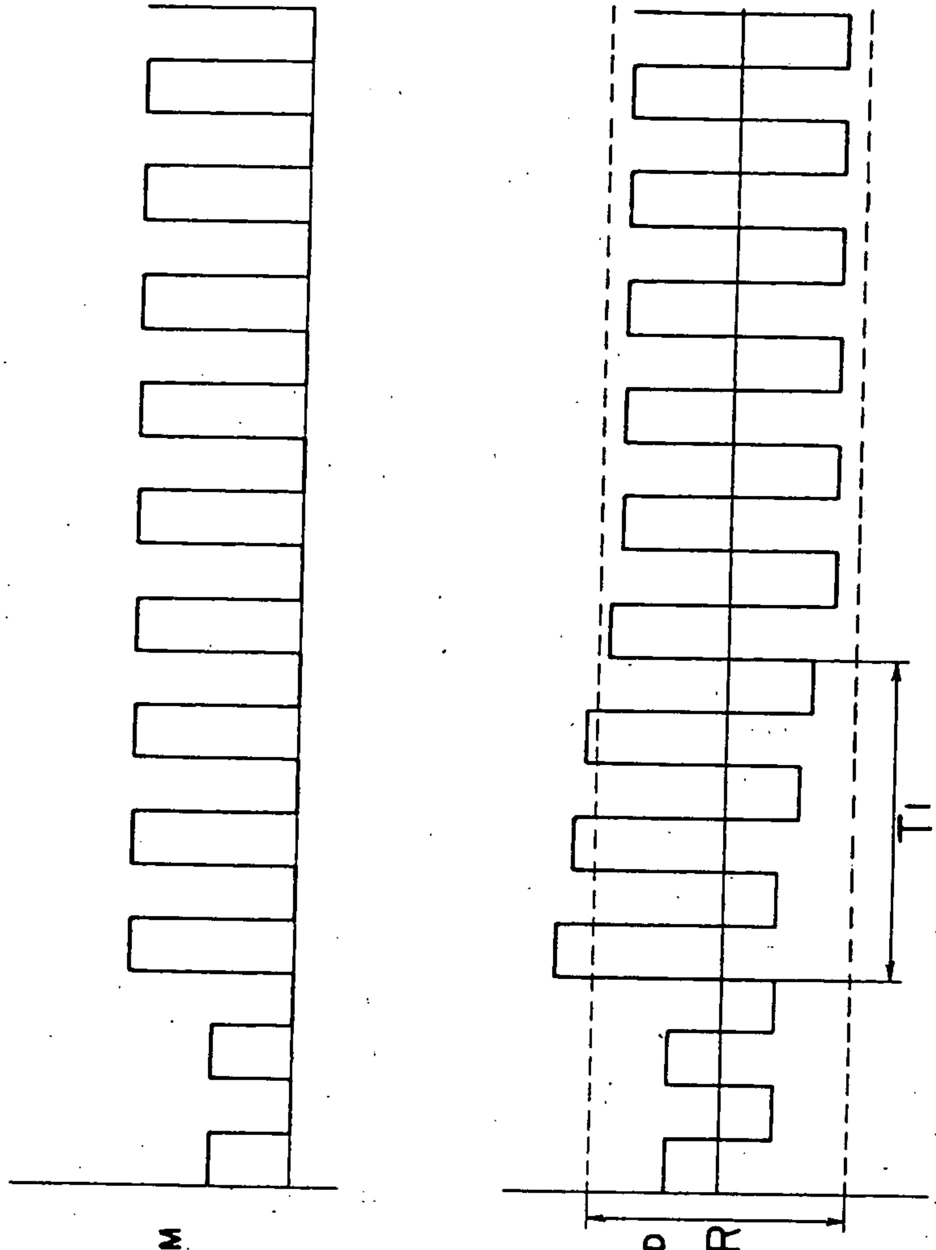
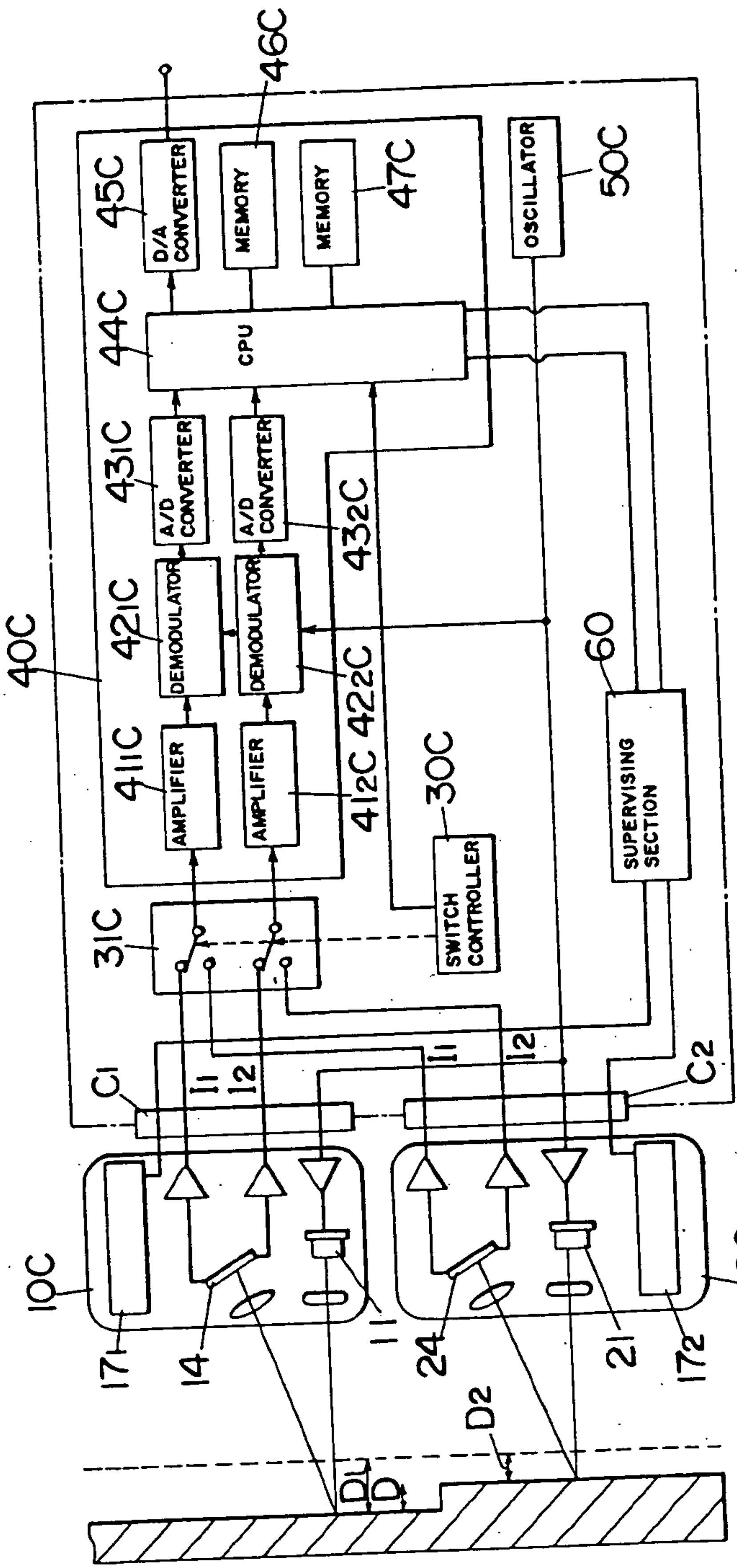


Fig.9A LASER BEAM RECEIVED AT PSD

Fig.9B SAMPLE-AND-HOLD CIRCUIT OUTPUT

Fig.9

Fig.10


D/A CONVERTER
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MEMORY
OSCILLATOR
CPU
A/D CONVERTER
A/D CONVERTER
DEMODULATOR
DEMODULATOR
AMPLIFIER
AMPLIFIER
SWITCH CONTROLLER
SUPERVISING SECTION
46C
45C
47C
50C
44C
431C
432C
421C
422C
411C
412C
40C
30C
31C
60
C1
C2
11
12
10C
20C
17₁
14
24
21
17₂
DL
D
D2

Fig.11